Research and trends of optical transport networks

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Abstract

The IST project NOBEL phase 2 has addressed the evolution of transport networks in Europe in terms of architectures, traffic engineering and economics, control plane and transmission technology issues. This paper presents the main project results, highlighting the major technical problems and the related solutions envisaged by the project.

Introduction

The growth of transport networks in Europe has recently assumed a more gradual and stable trend, and it is now definitely oriented towards the support of broadband services to a wide mass of European citizens. This evolution is lead by a few elementary drivers: to improve quality and efficiency in providing current and new services; to optimise the use of resources; to limit the operating costs.

These general objectives require a full revision of network architectures and technologies, a close integration of IP and transport layers, including advanced Control Plane interworking, and an easy, automated management of optical circuits for fast provisioning and restoration. The Integrated Project NOBEL phase 2 has focused on these objectives, carrying out analysis, feasibility studies and experimental validations of innovative network solutions and technologies for flexible, scalable and reliable optical networks. This paper presents the key outcomes of the project in the areas of integrated network architectures, network engineering, burst/packet networks, control and management planes, and optical transmission technologies.

Architectures of future integrated broadband networks

Telecommunication networks evolution is driven by two basic needs: an enhanced dynamicity of connections and a reduced cost of ownership, enabling a lower industrial cost of network services.

The key leverages to achieve these results are: packet technologies (in particular IP/MPLS and a strong improvement of Ethernet), Control Plane (ASON architecture and GMPLS paradigm) and optical transparency (to save the regenerators cost).

Traditional IP/MPLS and Ethernet are defined to assure strong flexibility, but they do not guarantee the efficient OAM, quality performance and resilience mechanisms typical of circuit connectivity. For this reason, today's transport networks (both in the metro and in backbone segments) combine circuit transport networking (PDH, SDH, WDM and OTN) with packet networking. Emerging technologies (called Packet Transport Technologies - PTT) are going to be standardized. Operation, Administration, and Maintenance (OAM), and the Control Plane and Resilience Mechanisms of this emerging transport paradigm are the same as those of the original circuit transport networks, while the frame format, the statistical aggregation and the QoS support is similar to packet technologies, namely Ethernet for PBB-TE (based on IEEE802.1Qay) and MPLS for T-MPLS (based on ITU-T 8110.1).

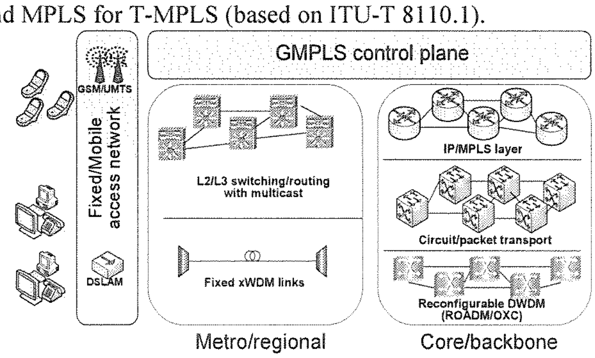

Figure 1 – metro and core target architecture

Figure 1 schematically depicts the target network architecture for metro/regional and core/backbone segments. In more details, the picture shows that different solutions have to be adopted in the metro and core segments. In fact, IPTV (multicast) will dominate the bandwidth consumption in metro areas. The coexistence of unicast network services (for Video on Demand, High-Speed Internet and Voice services) and multicast traffic (i.e. mainly IPTV), joint to the high level of dynamicity of the requested bandwidth, lead the metro architecture towards a solution where packet transport will dominate the scene. In metro segments, the main features of circuit switched networks (e.g. strong OAM and efficient resilience mechanisms) are suitably replaced by connection oriented packet-based connectivity at much lower costs.

Regarding OAM, and also resilience mechanisms, an interesting enhancement might be the substitution of traditional L2 or L3 packet technologies (Ethernet and IP/MPLS) with new packet transport (PBB-TE or T-MPLS) that assure a higher level of manageability and resilience.

For the core segment the situation is different, since the boundary conditions are not the same. First of all, multicast is not essential, and the bandwidth at stake is very large. For

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these reasons, in some cases, circuits might represent a good solution for the cheapest switching per bit/s.

On the other hand, considering the evolution of DWDM layer in a scenario with decreasing cost of bit/s (due to increase of the bandwidth per fiber and longer distances without intermediate regenerations) and the possibility to be flexible; this, joined with introduction of G.709, makes a scenario dominated by circuits attractive. On the other hand, the flexibility of packets, the possibility to have statistical aggregation, joined with the carrier class OAM and resilience mechanism offered by emerging packet transport technologies (PBB-TE and T-MPLS), leave open the diatribe between circuit and packet in the core segment.

Service-focused network engineering

Traditionally, different networks have been used for different services. Accordingly, each transport network has been specifically designed in order to fulfil the survivability and QoS requirements of specific applications. For example, while NG-SDH networks were designed to support real time traffic with strict requirements in terms of delay and availability, packet transport technologies were initially used to support best-effort Internet traffic. However, current network trends indicate an evolution towards a common multiservice IP network that is able to support any kind of service over the same infrastructure. Main drivers for a common transport network are the CAPEX and OPEX savings achieved by simplifying the transport network infrastructure. However, this evolution also presents important technical challenges, since the QoS and survivability requirements of each service should still be fulfilled in the most cost-effective way.

In that respect, current IP backbones, often based on hierarchical architectures and static point to point links between routers, present scalability problems, mainly due to the increase of pass-through traffic. In order to solve this problem, operators are starting to deploy "intelligent" transport networks based on TDM and OTN equipment with GMPLS functionalities. Thus, with the appearance of IP over GMPLS networks, the number of technical alternatives for resilience and Traffic Engineering is increased. In pure IP networks, all the network engineering mechanisms are exclusively done at the IP layer, while in IP over GMPLS both Traffic Engineering and resilience mechanisms can be carried out in different transport layers (L0/L1/L2/L3). Furthermore, such resilience and traffic engineering could be executed in an independent or coordinated way. On account of this, some questions arise: How can we assure the required QoS and survivability for each application over a multiservice transport network? Do we need resilience and traffic engineering mechanisms at each layer? In such case: What are the recommended mechanisms?; Should we coordinate them in some way?; How?

The FP6 NOBEL2 project has already provided some answers to these questions:

QoS-based resource allocation and admission control strategies are required in order to optimize the resources consumption while respecting the QoS. In particular, NOBEL 2 has defined advanced routing and CAC (Call Admission Control) mechanisms for IP over GMPLS metro and/or core networks. These mechanisms include possible redistribution of bandwidth between pairs of edge routers in the GMPLS network and redistribution of bandwidth between QoS classes, and may be triggered by scheduled events and observations of the traffic in the network. Furthermore, routing algorithms for all optical networks, minimizing the blocking probability, have also been investigated.

NOBEL 2 has defined a QoR (Quality of Resilience) framework which enhances the used QoS dimension (e.g. delay, packet loss) by providing a new dimension of the SLA in terms of service availability and traffic loss. Poor availability leads to customer churn or no acceptance of the IP based services (e.g VoIP service). So, a solution is presented in NOBEL 2 based on a set of QoR parameters and monitoring mechanisms that can be used in order to assure the required network survivability and end user availability perception for each service

Multilayer resource allocation mechanisms based on an integrated control of packet and circuit (e.g. optical) resources can optimize the total network resources as well as the end to end delay. In that respect, it is of paramount importance to define a good policy for selecting the proper network layer to accommodate a new request in the most efficient way. Therefore, NOBEL2 proposes novel algorithms to dynamically adjust the layer selection policy.

Different recovery strategies can be used in IP/MPLS/OTN. For example:

- Scenario 1: Optical Sub-Connection Recovery: Recovery at the transport layer (OTN)
- Scenario 2: End-to-End Optical Connection Recovery. Resources allocated or soft-provisioned at the optical level for end-to-end path recovery purposes can be re-used at the packet level to allow for local path recovery.
- Scenario 3: End-to-End Packet Connection Recovery. End-to-end protection on the IP/MPLS layer

The multilayer approach in scenario 2 drives the total number of node interfaces down by approximately 30% from the two other scenarios. The recovery duration for the three recovery scenarios are of the same order of magnitude. Scenario 2 provides an optimal solution in terms of signalling function complexity and protecting resource requirements.

However, multi-vendor implementations of vertically integrated multilayer traffic engineering mechanisms would require a strong level of standardization. Therefore, these mechanisms might be commercially deployed in the long term. On the other hand, multiple single layer mechanisms at different layers would be available in the short term. Some of the single layer resilience and TE mechanisms proposed in NOBEL2 are as follows:

- TCP dynamic policer which optimizes throughput while minimizing the negative effects of already existing solutions

- Optical routing algorithms based on PBR (Prediction Based Routing) and GoS (Grade of Service) strategies.
- Resilience mechanisms for transparent and semitransparent networks based on DSP (Demand-wise Shared Protection) or MPP (Multi-Path Protection) algorithms.

Burst/Packet networks for extended long term scenarios

NOBEL2 considers advanced burst and packet switching techniques as a main driver of the evolution towards new optical transport networks in metro and core and the suitable technology for future converged networks, supporting both circuit and packet based services. A flexible and scalable multi-layer architecture, with advanced burst/packet switching in Layer 2, will provide the required carrier grade quality and reliability level at very attractive costs, also for the dominating IP based services. This can be achieved by using the Layer 2 for bypassing the expensive Layer 3 IP routing functions with the transit traffic, thus enabling end-to-end connections in Layer 2, supporting any required class of service.

The work is based on the first network and node architectures elaborated in NOBEL phase 1, which are further refined and detailed and put in perspective to evolution scenarios for the extension of existing networks and nodes, for a smooth transition towards the next generation optical internet. These draft solutions of flexible and scalable structures, based on an optimal mix of optical and electronic technologies, are being further elaborated and detailed based on technology assessments. The goal is to achieve the highest benefit, both from the transparent optical bypass switching of transit traffic in a node as well as the unsurpassable signal processing capabilities of electronic routing/switching blocks. New approaches for optical burst switching (OBS) networks, characterized by efficient and high performance solutions, and adapted to opto-electronic technologies, are being studied.

The evaluation of burst/packet network and node architecture solutions is based on commonly defined reference networks and suitable traffic matrices reflecting realistic traffic profiles. A national 38-node packet transport network with dynamic traffic matrix, derived from real measurements, was provided as reference for dimensioning studies. Intense studies on the dimensioning of realistic carrier grade packet transport networks are being performed to elaborate dimensioning rules to ensure QoS in burst/packet networks with statistical multiplexing. A new dimensioning method for core networks has been defined, solely based on parameters already known or measurable by network operators. A common set of service classes, together with their bandwidth and QoS requirements, is being defined to build realistic scenarios in terms of network types and business models for the dimensioning studies. Techno-economic studies on the exploitation of OBS techniques also in metro rings showed their potential, in particular for dynamic and distributed traffic.

A critical point for the introduction of burst/packet switching techniques in Layer 2 is their potential impact on well established higher layer protocols, in particular the TCP protocol which is widely used for data transfer by IP based services. The behavior of various TCP flavors operated over Layer 2 burst/packet networks is being studied, and the impact of specific characteristics of burst/packet networks like burst losses, routing mechanisms and burst reordering problems on the overall performance is under evaluation. It could be shown that a burst/packet layer properly dimensioned for QoS will not have any major impact on the TCP performance.

Novel solutions for network control and management functions specific to burst/packet switching networks are essential to provide end-to-end high quality broadband connections and ensure the multi-layer interworking. NOBEL2 studies extensions to control and management functions covering routing, multi-layer traffic engineering, performance monitoring, and protection and restoration issues in hybrid burst/packet/circuit networks and defines procedures, algorithms and protocols to support QoS features in the optical burst/packet domain, compatible to existing synchronous networks and compliant with the demands of future broadband services over the Internet protocol. As an important point here, the compatibility of today's GMPLS functionalities with burst/packet switching networks is under study, and new requirements and extensions of GMPLS to cope with the new functionalities of Layer 2 burst/packet switching are being identified. The existing GMPLS control plane framework supports connection oriented burst/packet networks quite well, and only minor modifications will be necessary to fully support this technology. Modifications include the interpretation of labels and a new or reused RSVP object to indicate to which service class the label switched path belongs. A complete model for the integration of the burst/packet layer into the GMPLS control plane is currently under preparation.

The exploitation of an extended GMPLS-UNI for multi-layer recovery was studied to provide inter-layer communication in the control plane and ensure optimized network resource utilization and scalability. An integrated multi-layer recovery approach, in which the recovery capabilities of all involved layers are fully controlled and co-ordinated by means of a parameter driven process, was elaborated. In simpler failure cases, short recovery times can often be realised with actions on lower layers. In more complicated failure schemes, success is still guaranteed with a layer co-ordinating process, at the cost of a longer recovery period, but often with less resource consumption as well.

Different routing strategies for burst/packet networks have been proposed and evaluated. New adaptive routing strategies could bring benefit for dynamic traffic cases. A new approach for preventive resource reservation could considerably improve the loss probability for premium traffic in burst/packet networks.

Existing and upcoming standardization in the field of packet transport networks and their control are continuously assessed to identify possibly required extensions, allowing the smooth introduction of advanced burst/packet switching techniques into existing and evolving networks.

Integrated Network Control and Management Supporting Multilayer Networks

In order to attain the benefits and service offering potential of the advanced electrical and optical switching, transmission, and interface solutions, NOBEL2 pursues the design, evaluation, and deployment of edge-to-edge network control and management solutions. The convergence and functional layering trends also apply to the control and management area. By finding new ways of generalizing, integrating, and reusing control and management functionality, CAPEX reduction can be achieved, not only related to the data plane itself, but also related to the control and management solutions. Moreover, the advanced control and management solutions should enable further automation of the provisioning, multilayer (ML) TE, service assurance and other management and operational tasks. Accordingly, significant CAPEX and OPEX reductions can be achieved, while increasing overall network robustness.

In addition to the above drivers, the NOBEL2 control and management solutions must take into account potential new and innovative services as well as end-to-end application requirements. Supporting dynamic connectivity services, and also new bandwidth-greedy retail services, is an important motivation for NOBEL2 in acquiring knowledge, performing analysis, and proposing solutions suitable for standardization. In the following, important open issues, goals, and proposed approaches, as well as achieved and ongoing work by the project, are presented.

The basic GMPLS control plane (CP) architecture [1] and protocols (signaling and routing) constitute the starting point for the project. The applicability of GMPLS to the sub-IP switching capabilities and technologies makes it a unique enabler. GMPLS is essential for providing a way to optimize ML network technologies and to utilize their full potential. Without relaxing the use of GMPLS-based solutions for control of a single switching capability layer, we have investigated solutions for truly integrated ML TE. However, there are still several challenges that need to be solved to make GMPLS a comprehensive and harmonized ML solution. In the following, we point out the challenges that have required, or still require, investigation and solutions.

The CP must be able to handle topologies and related TE information of any applicable combination of single- and multi-switching type capable nodes. In Figure 2 we illustrate three base node (site) configurations that the CP solutions should handle. Interfaces of multi-switching type capable nodes provide a richer set of functionality than traditional single switching capable nodes. Solutions are needed for representing and disseminating ML TE, cross-layer adaptation capability, and state information of such nodes and links, in an efficient and sufficient way. A virtual TE link, i.e. a potential lower layer LSP that is at the moment not actually set up, can be presented into the virtual network topology (VNT) of the upper layer. Subsequently, an upper layer LSP setup that uses such a virtual TE link, can cause *triggered signaling* to set up the lower layer LSP. Any lower layer LSP that is represented as a TE link in the VNT of the higher layer is a Forwarding Adjacency (FA) in this VNT, and a FA-LSP of the lower layer. If traffic is decreasing (temporarily), the traffic (and client LSPs) can be rerouted to free and automatically release the FA-LSP to let these network resources be used for other traffic demands. Release or retention of underutilized FA-LSPs is an operator policy decision. The (ML) TE triggering rules should also be flexible and configurable according to operator policy.

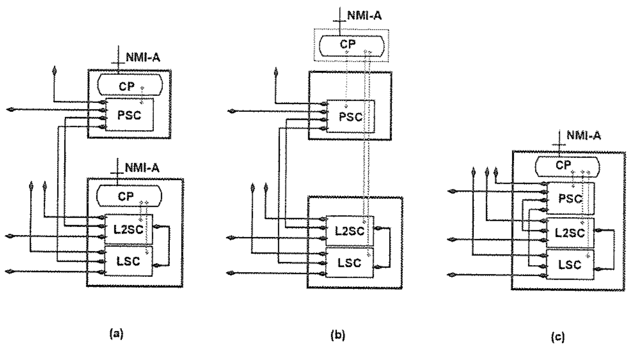

Figure 2 - Basic Node and CP alternatives

In addition to the ML TE control capabilities and aspects mentioned above, path computation in a ML environment is a challenge. NOBEL2 is exploring and assessing integrated ML TE routing strategies and approaches to path computation. By introducing the Path Computation Element (PCE), either in a distributed or a per-domain centralized fashion, the idea is to off-load LSRs and to allow multi-criteria constraint-based path computation, and hence improve the ML TE capability. We expect that the preferred PCE approach will depend e.g. on the network domain size, frequency of path requests, its switching capabilities, and the operator's routing and ML TE objectives. Thus, the CP solution must enable several ways of using PCEs. While every LSR does not any longer need to handle frequently changing network state and usage information, the PCEs must now handle and react to this information in a synchronized and more optimal way.

GMPLS-based VPN approaches have also been addressed by the project, as we expect such automated VPN services to become increasingly important. The GMPLS separation of control and transport planes raises new issues for the actual implementation, control, and management of customer specific control packets and channels. Customer end-to-end LSP establishment and server layer LSPs in a carriers' carrier environment, e.g. for the purpose of client network TE, requires triggered signaling and handling of the server layer LSPs as well as dissemination of topology, and/or reachability, and TE information dissemination by and via the Service Provider.

Support of delay-sensitive services has received special attention. Transport services with constraints in terms of delay are important for instance in support of advanced NGN services. Mechanisms are needed to determine and disseminate delay-related capabilities in different layers. A combined OSPF-TE and RSVP-TE solution has been proposed, and more detailed alternatives have been considered. ML and multi-domain issues have also been identified and ongoing work is addressing such issues.

We have also addressed issues and solution to adapt and extend the GMPLS protocols to support Layer 2 (Ethernet) solutions. To some extent, we have also addressed issues and approaches to enable migration and interworking between MPLS and GMPLS. We still observe that there are some key architectural challenges, so we do not expect to see IP/GMPLS multi-switching capable nodes with a unified CP in the market soon.

NGN and IMS-based architectures and solutions are hot topics in the Telco industry. Naturally, we have addressed architectural issues and solutions to improve and integrate network resource and access control when such environments are supported by GMPLS-driven network solutions. We have presented ideas of extending the NGN/RACF solutions that allow improved TE and the provisioning of GMPLS-based connectivity services to support advanced bandwidth greedy applications.

Above, we have mentioned several CP challenges to support ML TE and advanced service provisioning. The management plane must support, reflect, and control the capabilities of the CP. We have addressed both management and policy information modeling issues and required functionality on the associated management interfaces, e.g. supporting fault management in transparent optical networks. We expect policy-based management to play a vital role, supporting solution flexibility, automation, and operational efficiency.

In the last phase of NOBEL 2 we aim to continue the work on the above topics. Additionally, we will perform more targeted feasibility analysis, comparing the main ML TE enabled CP approaches, associated operational aspects, and CP performance studies. Directly or indirectly, we aim to continue dissemination of main results and solutions to the key standardization bodies.

Transmission technologies behind Broadband For All

As the physical layer forms the basis of all broadband networks, its further development forms an important part of the development of modern optical networks. All parts of a transmission system are constantly being adapted to reach one of the following goals, or a combination thereof:

- Higher data rate
- Longer reach
- Impairment robustness
- Low Capex and Opex
- Performance tailored to the target

The latter point means that it is not always reasonable to deploy the technically best solution, but rather the solution which just meets the target specifications (including margins, of course), offering the best compromise between price and performance.

Within the Nobel 2 project, a number of technologies are being researched to form a toolkit from which the suitable set for the particular network design can be selected. Those technology areas include:

- Electronic signal processing and electronic distortion mitigation. As the performance of electronic signal processing is continuously increasing, the well known signal processing technologies from the radio frequency domain can be introduced into the optical domain, offering (potentially) cheap and powerful means for (tunable) dispersion and PMD compensation or to compensate for imperfect components, i.e. direct modulated lasers at high bit rates. Coherent detections gains new strength by electronically correcting local oscillator impairments.
- Optical distortion mitigation. The decreasing birefringence of new optical fibers, to eliminate the effects of PMD, is counteracted by the increase of the data rates to 40 Gbit/s or even higher. Therefore, PMD compensation stays an important topic. Apart from electronic PMD compensators, a number of optical schemes are researched for their suitability for current and future transmission systems in combination with advanced modulation formats and electronic schemes. Again, as the technologically best solution tends to be economically unrealistic in most cases, the best compromise between the PMD compensator performance needed in the respective case and the economic constraints are being researched.
- Modulation formats have been on the agenda for a long time, but are still an important topic as high bit rates, dense DWDM channel spacing in combination with (R)OADMs, and the advent of electronic processing require and enable optimized modulation formats. Among the topics covered within Nobel 2 are the evaluation of various types of Duobinary modulation formats facing transmission impairments, phase modulation techniques for On-Off Keying, PMD tolerance of modulation formats at 43 Gb/s and beyond, DPSK receiver concepts with optical filtering, performance analysis of POLMUX-DQPSK and 16-DPOLSK and optical transmission Systems using multi-level modulation formats and electronic distortion equalization.
- Optical Performance Monitoring (OPM) investigates the needs and specifications of OPMs in transparent optical networks. The ideal case of a precise OPM at every network node is not economically feasible, therefore optimized OPM placements strategies together with relaxed OPM precision requirements are the best techno-economic solution.
- Routing and Wavelength Assignment (RWA) and Wavelength dependent reach: in a WDM system, different wavelengths have a different reach because of physical reasons like the EDFA gain profile and Raman inter-channel gain. Clever use of these properties in the RWA algorithms

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significantly reduces the cost/performance ratio. A number of different algorithms are being compared to figure out the best algorithm for a given network planning scenario.

Nobel 2 does not concentrate on a single technology but rather on a broad scope of possibilities and, as technology just for technologies' sake is not sufficient at the end, it concentrates on finding the right combination of technologies for a given scenario, whether upgrading an existing network or planning a green field approach.

Conclusions

In more than one year of work, NOBEL phase 2 has reached many challenging objectives: the definition of network solutions and evolutionary guidelines for both core and metro optical transport networks based on ASON/GMPLS; the identification of solutions and technologies for physical transmission in transparent optical networks; the development of cost-efficient networks paradigms, network node architectures, and concepts for advanced optical packet/burst switching. In the near future, NOBEL phase 2 will complete its research with the development of flexible and bandwidth-efficient strategies for the end-to-end management and control of intra/inter-domain connections in multi-layers networks. Finally, the specifications required by such novel network applications will be identified, and feasibility studies will be carried out for the design of multi-service network node architectures.

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